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Cryogenic sampling of frazil ice deposits

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PREFACE

This report was prepared by Edward F. Chacho, Jr., Research Civil Engineer, Bruce E. Brockett, Physical Science Technician, and Dr. Daniel E. Lawson, Research Physical Scientist, all of the Geological Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for the research was provided by the Office of the Chief of Engineers, through the *Cold Regions Hydrology Program* under Civil Works Work Unit CWIS 31722, *Geomorphic Factors Affecting Sediment Transport and Deposition in Northern Rivers*.

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Cryogenic Sampling of Frazil Ice Deposits

EDWARD F. CHACHO, JR., BRUCE E. BROCKETT AND DANIEL E. LAWSON

INTRODUCTION

Studies of cold regions rivers have indicated the importance of frazil ice deposits in determining their winter regime. Frazil ice commonly deposits as hanging dams, anchor ice or longitudinal bars (e.g., Michel 1971, Lawson et al. 1986a). A frazil ice deposit may contain variable distributions of ice particle size, density or porosity, and sediment concentration. Our studies on the Tanana River near Fairbanks, Alaska (Lawson et al. 1986b) have shown that we need to fully analyze these properties to determine the history of the deposit and its influence on the hydraulic and morphologic characteristics of the river. Methods of sampling frazil ice deposits have been developed that employ a volumetric coring approach (Rand 1982, Brockett and Sellmann 1986, Dean 1986). These methods utilize various size samplers and techniques to acquire a core of the water-frazil ice mixture composing the deposit, and provide a bulk sample of the water and ice particles for analysis, but they can not retain the overall structure of the deposit. The cryogenic sampling technique, described in this report, freezes, in-situ, a vertical column through the frazil ice deposit, including the uppermost sediments of the riverbed and any open water. The resulting samples retain both the composition and the structure of the frazil ice deposit and the underlying bed material.

Portable cryogenic devices have previously been used for sampling streambed sediments. There are two basic designs, depending on the cooling agent used: liquid nitrogen (Stocker and Williams 1972, Knaus 1986) or liquid carbon dioxide (Walkotten 1973, 1976). The latter design is simpler and safer to operate and the cooling agent is readily available and conveniently transportable. This technique is an effective method of obtaining nearly undisturbed, stratified samples of the streambed during open water conditions (Carling and Reader 1981) and has also been used under winter conditions to sample the streambed of ice-covered channels (Lotspeich and Schallock 1974). The cryogenic frazil ice sampler described in this report is a modified

design based upon the cryogenic streambed samplers of Walkotten (1976) and Carling and Reader (1981).

SAMPLER DESCRIPTION

The sampler (Fig. 1) has a coaxial tube design. The outer tube or probe is inserted into the frazil ice deposit and freezes the surrounding material to the tube by releasing liquid CO_2 to atmospheric pressure inside the probe. The resulting pressure drop and vaporization of the liquid CO_2 cause a rapid heat loss, quickly freezing a core of material to the outer surface of the probe. As the freezing front progresses laterally, a sample of increasingly larger diameter freezes to the probe, the thickness of which is governed by the duration of CO_2 flow. The heat flow calculations for freezing streambed sediments have been described by Platts and Penton (1980); the reader is referred to this reference for details.

An essential requirement for accurate profiling of frazil ice deposits is that samples must span the full thickness of the deposit. Therefore, we constructed sampler assemblies in different lengths to afford full penetration of the frazil ice deposit using a single sample probe. Probes or outer tubes, ranging in length from 1.2 to 3.7 m, were constructed of either 25-mm-diameter, 3.2-mm-wall-thickness stainless steel tubing, or 1.9-mm type "M" rigid copper pipe. One end of the probe was sealed with a conical point. The higher thermal conductivity of the copper probe had no apparent effect on the efficiency of the sampler, which is in agreement with observations made in streambed sampling (Lotspeich and Reid 1980).

As Walkotten (1973) used in his improved streambed sampler, we used an inner tube or manifold in an attempt to distribute the CO_2 evenly over the effective sampling area and thus produce more uniform heat removal over the full length of the probe. The gas release manifold was constructed of 9.5-mm-diameter, 3.2-mm-wall stainless tubing plugged at one end. In the short version, meter-

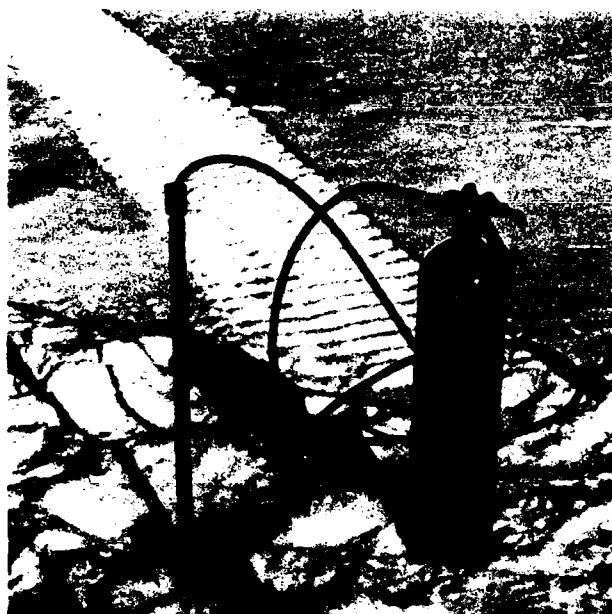


Figure 1. Carbon dioxide cryogenic sampling system in use on the Tanana River, Alaska.

ing nozzles with 0.15-mm-diameter holes were spaced 50 mm apart and, in the longer version, 0.15-mm-diameter holes were drilled through the manifold wall at 100-mm increments; in both cases they were offset every 120° in a spiral pattern over the full length of the manifold. As recommended by Walkotten (1976) the 50-mm spacing is preferred, as the 100-mm spacing produced samples of nonuniform diameter. A quick-disconnect high-pressure hose fitting at the open end of the manifold connected to a CO₂ cylinder through a length of high-pressure hose. The sampler was easily assembled by inserting the gas release manifold into the sample probe and connecting the hose. In actual practice, the manifold was abandoned because of clogging of the holes, and the high-pressure hose was inserted directly into the probe, in a way similar to the earlier streambed sampler of Walkotten (1973). The gas was released at the bottom of the probe, flowed over its full length and escaped to the atmosphere from the open end of the probe. Although CO₂ usage is probably less efficient with this technique, adequate samples were produced and the clogging problem was eliminated.

SAMPLING PROCEDURE

The prototype frazil ice sampler was field tested and evaluated in frazil ice deposits along surveyed cross sections on the Tanana River near Fairbanks,

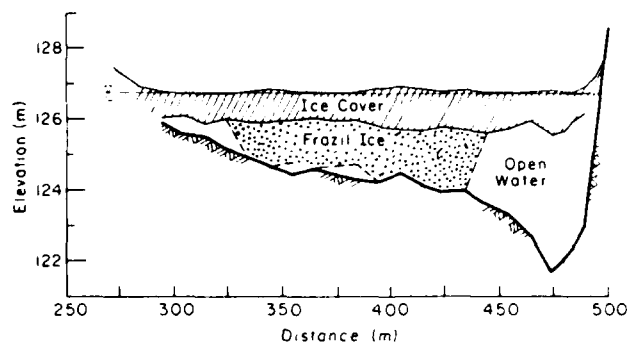


Figure 2. Typical winter cross section with extensive frazil ice deposits, Tanana River near Fairbanks, Alaska, in March 1986.

Alaska, where the locations and dimensions of large frazil ice bars had been physically measured (Lawson et al. 1986a), as well as remotely located by the magnetic induction conductivity method (Arcone et al. 1987) (Fig. 2).

To obtain representative samples of the in-situ composition of a frazil ice deposit, the following must be considered:

1. The structure of the deposit is relatively fragile.
2. Individual frazil ice particles are buoyant and largely unconsolidated.
3. The density, grain size distribution and sediment concentration may vary greatly throughout the deposit.
4. The deposit may be contiguous with the bottom of the ice cover but have water below it (hanging dam), it may be continuous from the bottom surface of the ice cover to the streambed, or it may lie on the streambed but with water above it (anchor ice).
5. The deposit may be stratified; therefore, we must know the orientation of the sample.

In sampling frazil ice deposits underlying a solid ice cover, the first step is to provide access holes through the ice cover without disturbing the frazil ice particles or causing redistribution of sediments that may be contained in the interstitial water of the deposits. To accomplish this, the thickness of the ice cover adjacent to the sampling area is determined using a CRREL ice thickness kit (Ueda et al. 1975). A 204-mm-diameter sample hole is then augered to within 50 mm of the measured ice thickness and charged with cold water to prevent a hydraulic surge when the ice cover is finally penetrated.* To limit disturbance caused by removing the remaining 50 mm of ice, a special-purpose core barrel (Fig. 3) was developed (Brockett

*Personal communication with Paul Sellmann, CRREL, 1986.

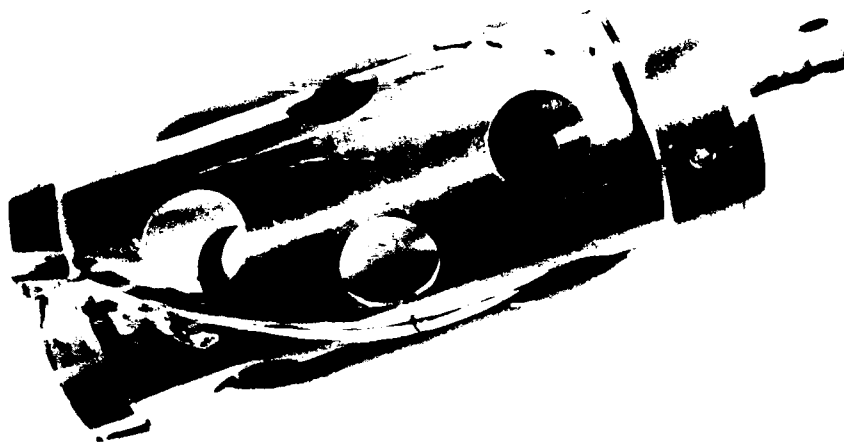


Figure 3. Special-purpose short core barrel (152-mm diameter, 216 mm long), designed to remove the bottom plug in sample access holes.



Figure 4. Example of a frazil ice sample. Scale in inches and centimeters.

1986). This core barrel has a shallow depth of cut and is turned by hand. Observations indicate only minor disturbance of the upper layer of the frazil ice deposit was produced by this procedure. When open water overlies anchor ice, sampling is much simpler since access through an ice cover is not needed.

After access to the frazil ice deposit is established, the sampler probe is slowly inserted through the frazil ice deposit and into the bed material. Care is taken to maintain a vertical orientation during insertion to minimize the displacement of ice particles in the path of and adjacent to the probe. The gas release manifold, if used, or the high-pressure hose

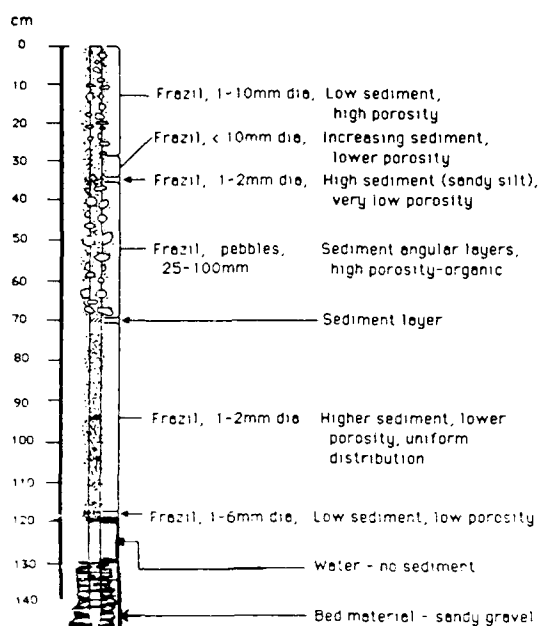


Figure 5. Typical log description of a frazil ice deposit sample.

is inserted into the probe and CO_2 flow started. The CO_2 flow rate is regulated with a valve on the supply tank. The consumption of CO_2 ranged from 2.3 to 6.8 kg for increments of 1 to 2 minutes. After CO_2 discharge is complete, slight rotational force on the probe (less than 45°) may be necessary to break the sample free to allow extraction from the frazil deposit.

After extraction, loose ice particles collected on the sample while it is pulled out of the deposit must be removed before becoming frozen to the sample. During the field tests, we simply brushed away the loose material as the probe was being extracted. However, during sampling periods with lower ambient air temperatures, a faster method of removal may be necessary. One possible method is the use of a small, portable air compressor to blow the sample clean.

While frozen to the probe, the samples are easily handled and laid out for photographic and written logs (Fig. 4 and 5). The copper probes required careful handling as flexing of the pipe caused small concentric cracks to form in the samples. The greater rigidity of the stainless steel probes allowed for rougher handling of the samples. The heavier stainless steel probes are also easier to insert vertically into the deposits as penetration is largely accomplished by the probe weight; the copper probe has a tendency to waver as it pushed through the deposit. We removed the samples from the probe by pouring warm water into the outer tube and sliding the sample off the end. The sample remains intact in the form of frozen, hollow cylinders (Fig. 6), maintaining the ice and sediment stratigraphy.

During the freezing process, the lateral advance of the freezing front is rapid and gases dissolved in the interstitial water are trapped within the newly formed ice as minute gas bubbles, resulting in a

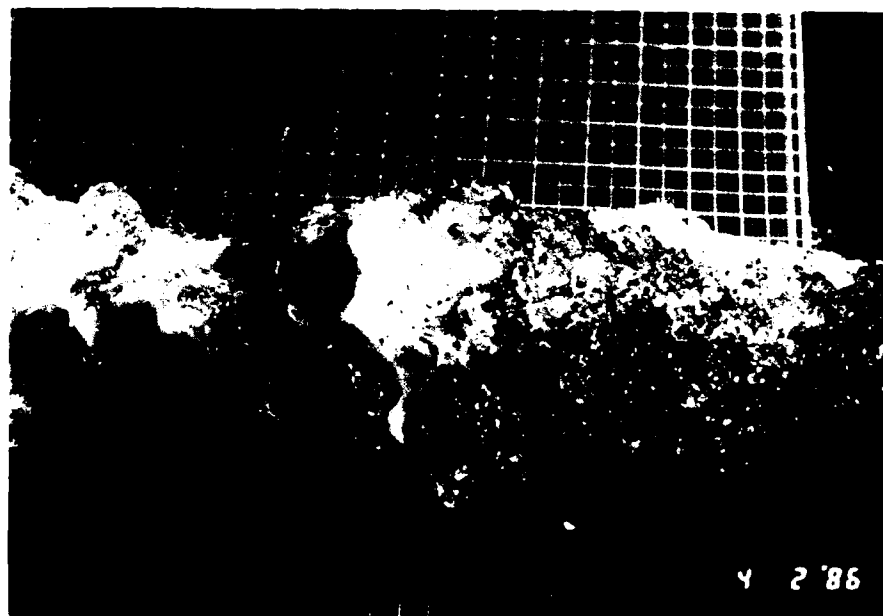


Figure 6. Deposit sample removed from probe showing individual frazil ice particles outlined against the milky white interstitial ice. Variability in ice particle sizes and structure is apparent.

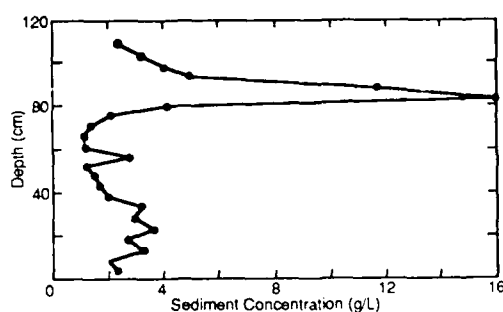


Figure 7. Vertical profile of sediment concentration analyzed from probe sample.

milky white color. The frazil ice particles remain clear, readily defining the grain boundaries of all previously existing ice particles (Fig. 6). In flowing water, the ice that forms on the probe is clear on the upstream side, while it is milky white on the downstream side.

The sample can be removed from the probe, sectioned in the field and stored in plastic bags for later analysis. Laboratory analysis may include measuring profiles of sediment concentration (Fig. 7). Since the measurement of sediment concentration is destructive, the procedure we employed was to bisect the sample lengthwise, using one half for sediment analysis, while retaining the other half for nondestructive analyses. These analyses may include identifying ice types or observing in detail the structure and stratigraphy of the deposit defined by multiple probe samples. For instance, frazil pebbles (Chacho et al. 1986) can be cut for thin sectioning and composition analysis, or the entire sample can be thin sectioned to analyze ice grains or other properties. Similarly, quantitative stereological techniques may be applied to determine a vertical profile of the porosity or density of the frazil ice deposits.

EVALUATION

The cryogenic sampling technique is a rapid, simple method for obtaining representative samples of the in-situ structure and general composition of frazil ice deposits. However, three operational problems were identified during the field tests: 1) clogging of the jets in the gas release manifold, 2) inefficient use of CO_2 , and 3) sample removal in the field. As described above, the expedient solution to the first problem was to remove the gas release manifold from the system. This led to greater inefficiency in CO_2 usage but produced adequate samples at a reasonable cost. Both problems may be

eliminated by adoption of a pressurized CO_2 liquid-gas system described by Platts and Penton (1980). The third problem concerns the use of warm water to remove the samples from the sample probe at the field site, particularly during periods of extreme cold. During extensive sampling programs this method may be too time consuming to be of practical use. Alternative methods of sample removal should be considered, such as the use of electric heat probes or forced hot air. More simply, a large number of sampler probes could be used and the samples removed in the laboratory.

One problem that affects the macroscale quality of the samples is a minor reorientation and displacement of ice particles that occurs in the path of the sampler probe during insertion into the deposit; this effect, however, is readily identifiable. By increasing the duration of CO_2 flow, a larger diameter sample of the undisturbed ice can be obtained; however, further work is needed to define the optimum CO_2 flow duration.

The fast freeze process may affect the microscale quality of the samples. At this time the potential effects of rapid freezing on individual frazil ice particles (such as cracking of large particles or distorting the spatial relationship of particle clusters as interstitial water freezes) are unknown. Additionally, there is a question of whether sediment is excluded as the freezing front advances through the frazil ice deposit. Since the rapidity of the freezing front advance precludes expulsion of dissolved gases, it may be safe to assume that sediments would likewise not be excluded. In support of this assumption, Knaus (1986), using a liquid nitrogen sampler, observed no exclusion of fine sediments from ice crystals while cryogenically sampling streambed material in a glass-walled aquarium.

CONCLUSION

The cryogenic sampling technique obtains full depth samples representative of the in-situ structure of frazil ice deposits. The composition of the frazil ice deposit is also defined; however, access to individual ice particles is restricted since they are contained within a solid ice mass. The material within the deposit can be sampled in its natural state with a volumetric bulk sampler (Brockett and Sellmann 1986). Repetitive sampling of frazil ice deposits will provide data on the longitudinal, transverse and vertical variability of the deposit components, as well as information on the pro-

cesses affecting deposit growth and the metamorphic processes taking place within the deposit.

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